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Condition Assessment of Production Separators using Neuro-Fuzzy Tools for Signal Validation and Diagnosis

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Abstract

This paper describes a sub-activity within the CORD Production Separator project focusing on applying neural network-based signal validation and diagnosis tools for abnormality detection and condition assessment of the internal equipment of production separators in the petroleum industry.

The tools have been successfully applied for the monitoring of various processes within the nuclear industry, and perform their functions by learning how various process signals are correlated. PEANO will validate and calibrate a sensor by determining any deviations from the expected correlations to other sensors, while ALADDIN recognizes a fault by its associated time-based “signature” in the combined data matrix.

Keywords: neural networks, condition monitoring, petroleum, separators

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CONDITION ASSESSMENT OF PRODUCTION SEPARATORS USING NEURO-FUZZY TOOLS FOR SIGNAL VALIDATION AND DIAGNOSIS

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SUMMARY/ABSTRACT

Among the most crucial equipment to be found on offshore oil installations are the production separators, the purpose of which is to separate the mixture of crude oil, water, gas, foam, emulsion, sand and grit from the oil wells through gravity-induced coalescence. The very hostile operating environment, with high pressure and high temperatures, places heavy strain on internal equipment installed to facilitate the coalescence process, and makes the condition monitoring of said equipment extremely difficult.

Currently no standard condition monitoring method of separator internals exists, and only corrective maintenance is carried out during planned routine inspections, typically every 3 years (time based maintenance). As the maintenance shutdowns are associated with very high expenses (which can run at more than $10,000,000 per day), it is considered a high priority to both shorten the downtime and to lengthen the interval between shutdowns.

Condition based maintenance facilitates achieving both these goals by allowing maintenance planners to have the necessary spare part and repair equipment at hand, and by avoiding unnecessary maintenance shutdowns where the internals turn out to be in acceptable working condition.

This paper describes a sub-activity within the CORD[1] Production Separator project focusing on applying neural network-based signal validation and diagnosis tools for abnormality detection and condition assessment of the internal equipment of production separators in the petroleum industry. The tools have been successfully applied for the monitoring of various processes within the nuclear industry, and perform their functions by learning how various process signals are correlated. PEANO will validate and calibrate a sensor by determining any deviations from the expected correlations to other sensors, while ALADDIN recognizes a fault by its associated time-based “signature” in the combined data matrix.

The focus of the CORD Production Separators project is to investigate several technologies, including acoustics, microwave and gamma measurements, to perform condition monitoring of internal equipment. In the activity described in this paper it is proposed to combine the data from these technologies with standard process measurements, such as flow, pressure, temperature and composition at separator inlet and outlets, and apply them to the neural network-based tools to achieve reliable information regarding the condition of the internal equipment. This information can reveal possible sources of deficiencies, and thus help to assess the risks associated with different levels of the subsequent maintenance activities.

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[1] **C**oordinated **O**ffshore operation and maintenance **R**esearch and **D**evelopment

INTRODUCTION

One of the major obstacles to the successful planned maintenance of offshore oil installations is the condition monitoring of internal equipment of production separators. This equipment is subject to harsh conditions, while at the same time being completely inaccessible to maintenance personnel. Whenever maintenance is to be carried out on these separators, the entire productions must be shut down, at a very high cost.

The CORD Production Separator project is a continuation of the CORD Condition Monitoring project, and includes several activities to apply existing technologies (including the analysis of passive acoustics, active microwave and active gamma measurements) to remedy this situation.

The focus of an additional activity is to determine the feasibility of applying two neural network-based [1][2][3] software tools on the problem of condition monitoring of internal equipment of production separators, based on the successful application of these tools in the nuclear industry.

This paper will present the technologies under evaluations in the project, with primary focus on the software tools and the technologies used in their development.

THE TOOLS

The tools described below have been successfully applied for the monitoring of various processes within the nuclear industry, and perform their functions by learning how various process signals are correlated. PEANO [4] will validate and calibrate a sensor by determining any deviations from the expected correlations to other sensors, while ALADDIN [5] recognizes a fault by its associated “signature” in the combined data matrix.

PEANO

Physical processes, such as can be found in e.g. nuclear power plants and off-shore/onshore oil installations, are typically equipped with sensors positioned at strategic locations in the process, measuring data relevant for process control and monitoring. Due to the nature of such processes, variations occurring at one position in the process will cause variations somewhere downstream, which means that measurements from one sensor will typically show some correlation to measurements from other sensors (albeit with a time-lag). If a single signal starts to deviate from this correlation (either suddenly or over time), it is usually caused by a fault in the sensor.

The purpose of signal validation is to recognize if a sensor behavior significantly deviates from the behavior indicated by the history of the signal or by the expected correlation to other signals.

During recent years, an in-house developed software tool for signal validation based on neural networks and fuzzy / possibilistic logic has been used at the Institute for Energy Technology (also host to the OECD Halden Reactor Project). The tool, PEANO, has the ability to learn what constitutes normal operations by:

- separating the input data into clusters using fuzzy / possibilistic clustering techniques. Each clusters represents a particular operating condition.
- for each cluster developing an artificial neural net (ANN), learning the correlations between the signals, also with time-lag (see Figure 1).
- evaluating if a signal is within expected range.
- estimating correct value when a deviation occurs.

Clustering

PEANO performs 3 clustering operations on the available training data:

- **Crisp clustering.** Here the initial clustering is performed, and the borders between clusters are crisp.
- **Fuzzy clustering.** Here the borders are “softened”, and each data point has a degree of membership to each cluster. This method has the disadvantage that the cluster membership values for each data point must sum up to 1, which means that a stray data point may still have a high degree of membership to some cluster, even though it clearly does not belong there.

- **Possibilistic clustering.** This corrects the problem of fuzzy clustering by re-moving the constraint that the membership values must sum up to 1. Here a stray data point may have a zero membership value for all clusters, which amounts to an "I don't know" answer.

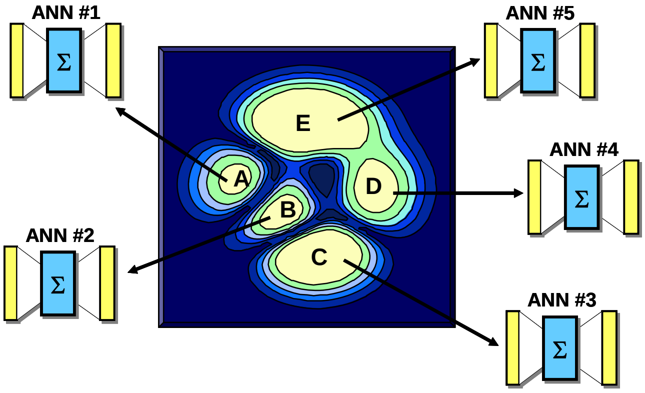

Figure 1. Possibilistic clustering and associated neural nets.

Artificial Neural Nets

For each identified cluster of data, an artificial neural net (ANN) is developed (see Figure 2). The net includes input/output layers, as well as 3 hidden layers. It learns using a feed-forward back-propagation learning rule.

The main advantage of using separate ANNs for each cluster (as opposed to training a single ANN to handle all data), is that if the operating conditions change, there is no need for re-training of the "old" net. It is just a matter of creating a new cluster, and developing an ANN for this cluster.

PEANO usage

The main PEANO algorithm consists of 3 stages:

- **Training.** In this phase the tool is presented with a training set for clustering and neural net generation. The data may be from different operating conditions, but must be clean in the sense that no sensor malfunctions/drifts are present.
- **Verification.** In this phase the tool is presented with a data set for verifying the correctness of the generated ANNs.
- **Monitoring.** In this phase the tool is continually presented with on-line process data (a newly developed module will also perform these calculations in off-line batch mode). Each data point is passed through the appropriate ANN (or ANNs, in cases where the data point is shown to "belong" to several clusters), and any deviation from the established correlation is identified.

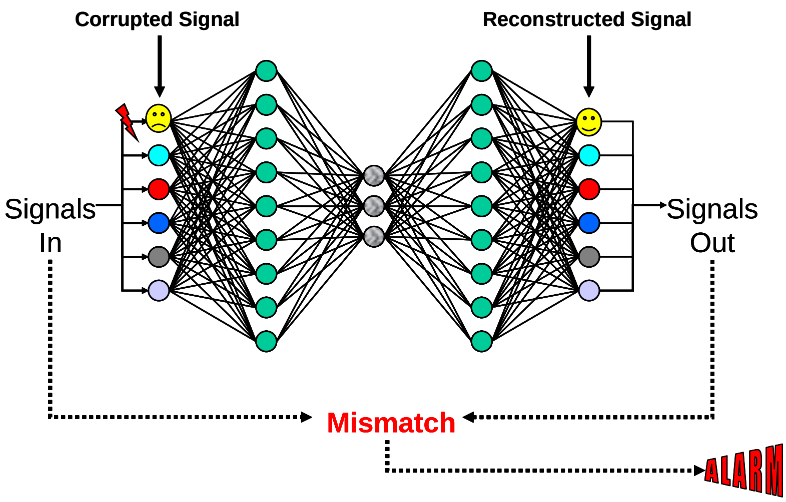

Figure 2. Artificial neural net for a cluster.

ALADDIN

Faults occurring in physical processes will typically affect more than one measurement (unless it occurs at the very end of the process), and different faults will affect the measurements differently, which means that each fault will have an associated “signature” in the combined data matrix.

The ALADDIN tool, which also has been developed and applied at the Institute for Energy Technology combines fuzzy clustering techniques and neural network models to perform event/transient classification in dynamic processes. By observing how a number of process variables change in time, ALADDIN identifies which fault could be responsible for those changes (see Figure 3).

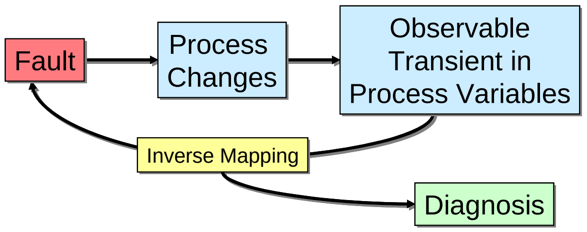

Figure 3. ALADDIN process.

The ALADDIN algorithm also includes a training phase, but unlike for PEANO, the training data must include the faults ALADDIN should learn to recognize.

THE DATA PROVIDERS

The process data available in the vicinity of a production separator typically includes:

- fluid flow rates (inlet, outlets)
- compositions (oil, water, gas)
- pressure
- temperature
- fluid level (at one or more points in the separator)

These data are directly applicable in the tools described above. In addition, the CORD project includes 3 other sub-activities focused on evaluating other hardware-based technologies for condition monitoring which may provide additional relevant data. These include acoustic measurements, microwave imaging, and gamma radiation detection.

Acoustics

The focus of this activity is the passive “listening” to sounds generated within the separator due to a number of factors, including fluid turbulence, bubbles, rumbling and creaking of loose equipment, and falling equipment.

A number of sensors are placed on the outside wall at positions calculated to provide optimal information regarding internal conditions.

One of the main challenges is to make the signal processing software sufficiently advanced to be able to estimate the condition based on the sensor signals and the interactions of the possible sound sources.

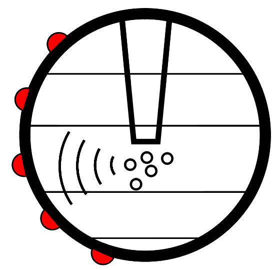

Figure 4. Acoustic sensors placed on outer separator wall.

Microwave

The focus of this activity is to use a microwave radar, based primarily on COTS[2] hardware modules, with specially developed signal processing software. Several microwave transducers, connected to a central signal generation and –processing unit, are placed inside the separator to determine structural changes based on distance measurements obtained by registering the echo of transmitted microwaves.

One of the main challenges is to make the detectors robust with regard to environmental factors and scaling.

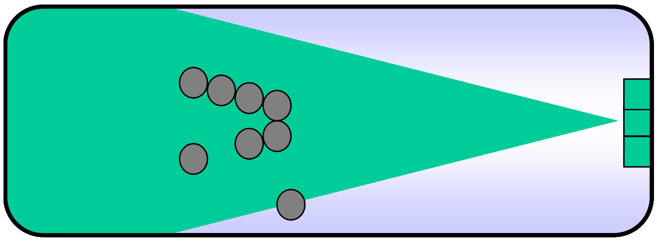

Figure 5. Microwave transmitter and detector array (separator seen from above, with one out-of-place inlet cyclone).

Gamma

Gamma radiation detection is primarily used for presence detection of internal equipment, and for gas carry-under determination.

Gamma radiation will be absorbed at different rates depending on the medium through which it passes, with metal having the highest absorption rate, followed by liquid (water and oil), and gas at a distant third.

A gamma source is placed on the outside of the wall, and an array of detectors at the opposite side (see Figure 6), with the equipment to monitor between. The radiation received at any of the sensors will increase whenever some internal equipment, composed of dense metal, is removed from the radiation's trajectory.

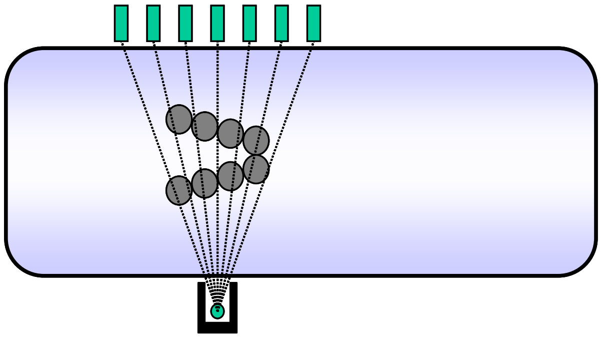

Figure 6. Gamma source and array of detectors for cyclone presence detection (separator seen from above).

THE USAGE

Figure 7 indicates how the disparate sources of process data, in combination with output from the described technologies, are used as input to PEANO and ALADDIN.

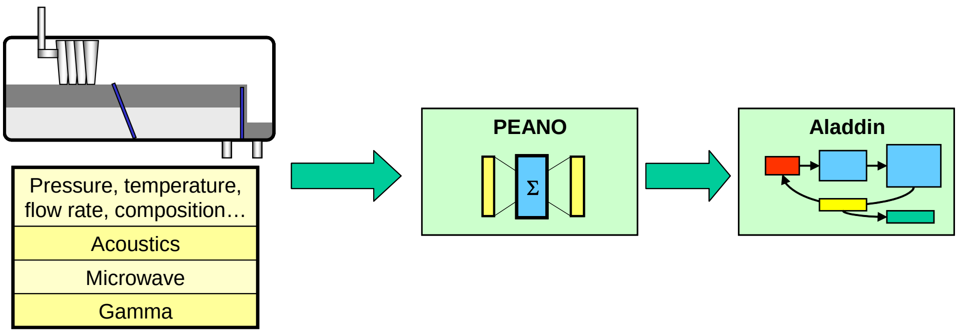

Figure 7. PEANO and ALADDIN processing data from a separator.

One of the challenges will be to determine the optimal parameters from these technologies to be used as input for the neuro-fuzzy tools. For the acoustic measurements, the parameters may be the decibel level (at selected

[2] Commercial Of-The-Shelf

wavelengths) or an abnormality-indicator from each sensor. For the microwave, it may be a matrix of distance measurements, while in the gamma case one may choose to use the individual sensor readings directly.

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